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13. ABSTRACT (Maximum 200 words)

During the course of the contract we developed a model, the master-slave system, to accurately model the scheduling problem that arises when a program running on a host processor initiates many tasks on an attached multiprocessor. Efficient algorithms to obtain optimal schedules were developed for some scenarions and approximation algorithms were developed for other scenarios.

We also developed efficient algorithms for sorting, selection and packet routing, matrix multiplication, and image processing tasks on parallel computers that employ all optical (e.g., array with reconfigurable optical buses) or optoelectronic interconnect (e.g., optical transpose interconnection system meshes and hypercubes).

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1 RESEARCH

The objectives of the contract were to develop new algorithms, data structures, and parallel algorithm design methodologies for SIMD and MIMD parallel computers.

During the course of the contract we reviewed the many performance metrics that have been proposed for parallel systems (i.e., program -- architecture combinations). These include the many variants of speedup, efficiency, and isoefficiency. We have found reasons why none of these metrics should be used independent of the run time of the parallel system. The run time remains the dominant metric and the remaining metrics are important only to the extent they favor systems with better run time.

We also laid out the minimum requirements that a model for parallel computers should meet before it can be considered acceptable. While many models have been proposed, none meets all of these requirements. The BSP and LogP models are considered and the importance of the specifics of the interconnect topology in developing good parallel algorithms pointed out. Our findings will be written up shortly and submitted for journal publication.

Effective scheduling of parallel computers is important to obtain good performance. We have developed a model, the master-slave system, to accurately model the scheduling problem that arises when a program running on a host processor initiates many tasks on an attached multiprocessor. The master-slave paradigm also finds application in semiconductor testing, machine scheduling, transportation, maintenance management and other industrial settings. In the master-slave model a set of jobs is to be processed by a system of processors. Each job consists of a preprocessing task, a slave task and a postprocessing task that must be executed in this order. The pre- and post-processing tasks are to be processed by a master processor while the slave task is processed by a slave processor. We are presently developing algorithms for this model.

Our work on algorithm development for different architectures focussed on sorting, selection and packet routing on the AROB (Array with Reconfigurable Optical Buses) model as well as on the OTIS (optical transpose interconnection system)-Mesh and OTIS-hypercube models. This work included the study of algorithms for the important bit-permute-complement (BPC) class of permutations and for matrix multiplication.

Towards the end of the contract period we focussed our attention on the OTIS-Mesh model. This parallel-computer model uses a combination of electronic and optical interconnect. Short connections are realized using an electronic mesh topolgoy and long connections are realized using the optical transpose topology. Efficient algorithms to perform many fundamental tasks such as sort, rank, shift, window sum, consecutive sum, adjacent sum, and random access reads and writes were developed last year. Algorithms for these fundamental tasks can be used to develop efficient algorithms for high-level applications such as those that arise in image processing.

We completed work on algorithms for various variations of the matrix multiplication problem (this work was begun in the preceding reporting period). These variations include vector $\times$ vector, vector $\times$ matrix, and matrix $\times$ matrix. Our work is aimed not only towards matrix multiplication when the problem size matches the computer size but also when the matrix size is much larger than the computer size. In addition, we have developed efficient algorithms for image processing applications such as histogramming, histogram modification, image shrinking and expanding, and the Hough transform.

Details of our algorithms can be found in the publications that have resulted from this contract.

2 Ph.D. Students Graduated

The ARO contract supported the following Ph.D. students who have all completed their dissertations.

(1) Venkat Thanvantri

(2) Seonghun Cho

(3) Chih-fang Wang

3 PUBLICATIONS

(1) Sartaj Sahni, Scheduling master-slave multiprocessor systems, *IEEE Trans. on Computers*, 45, 10, 1996, 1195-1199.

(2) G. Vairaktarakis and S. Sahni, Dual criteria preemptive open shop problems with minimum finish time. Naval Research Logistics, 42, 1995, 103-121.

(3) Sanguthevar Rajasekaran and Sartaj Sahni, Sorting and routing on the array with reconfigurable optical buses, 1996 IEEE Second International Conference on Algorithms & Architectures for Parallel Processing, ICA3PP, 217-224.

(4) S. Sahni and G. Vairaktarakis, The master-slave paradigm in parallel computer and industrial settings, Journal of Global Optimization, 9, 1996, 357-377.

(5) S. Sahni and V. Thanvantri, Parallel computing: metrics and models, IEEE Parallel and Distributed Technology, 4, 1, 1996, 43-56.

(6) Sanguthevar Rajasekaran and Sartaj Sahni, Sorting, selection, and routing on the array with reconfigurable optical buses. *IEEE Trans. on Parallel and Distributed Systems*, 8, 11, 1997, 1133-1142.

(7) S. Sahni and Chih-Fang Wang, BPC permutations on the OTIS-mesh optoelectronic computer. IEEE Conference on Massively Parallel Programming with Optical Interconnect, 1997, 130-135.

(8) S. Rajasekeran and S. Sahni, Computing on the array with reconfigurable optical buses, World Multiconference on Systemics, Cybernetics, and Informatics, Caracas, Venezuela, 1997, 459-466.

(9) S. Sahni and G. Vairaktarakis, Scheduling for distributed computing, Proceedings IEEE 6th Workshop on Future Trends of Distributed Computing Systems, 1997, 284-289.

(10) S. Rajasekaran and S. Sahni, Randomized routing, selection, and sorting on the OTIS-Mesh. *IEEE Trans. on Parallel and Distributed Systems*, 9, 9, 1998, 833-840.

(11) C. Wang and S. Sahni, Basic operations on the OTIS-mesh optoelectronic computer. IEEE Conference on Massively Parallel Programming with Optical Interconnect, 1998.

(12) C. Wang and S. Sahni, Matrix multiplication on the OTIS-Mesh optoelectronic computer. In review.

(13) Chih-fang Wang and S. Sahni, OTIS optoelectronic computers, in *Parallel Computing Using Optical Interconnections*, Kluwer, 1998, 99-116. Ed. Li and Zhenq.

(14) S. Sahni and C. Wang, BPC permutations on the OTIS-hypercube optoelectronic computer. *Informatica*, 22, 1998, 263-269.

(15) C. Wang and S. Sahni, Basic operations on the OTIS-Mesh optoelectronic computer. *IEEE Trans. on Parallel and Distributed Systems*, 9, 12, 1998, 1226-1236.

(16) C. Wang and S. Sahni, Image processing on the OTIS-Mesh optoelectronic computer. In review.